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RANGING AND HABITAT SELECTION BY ASIAN ELEPHANTS *ELEPHAS MAXIMUS* IN RAJAJI NATIONAL PARK, NORTH-WEST INDIA[1]

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We collected data on Asiatic Elephant *Elephas maximus* ranging and habitat selection in Rajaji National Park (RNP) in Uttarakhand state, India using radio telemetry from December 1996-March 1998. Elephant home ranges were estimated (using 100% Minimum Convex Polygon) to range from 188 sq. km to > 400 sq. km. We could not detect any difference between male and female home ranges. Summer ranges were the smallest due to limited availability of water in the study area; however, we could not detect statistically significant differences between sexes or seasons. The six Elephants that were radio-tracked for over two years showed variability in ranging patterns between the 1st and the 2nd years. The overall Elephant population used the *Shorea* vegetation significantly less than the other major vegetation types (*Shorea*-mixed, Miscellaneous and Mixed plantations). This was due to the higher diversity of Elephant food plants in *Shorea*-mixed and miscellaneous vegetation types when compared to *Shorea* vegetation type. However, radio-tracking data from individual female Elephants that had young calves at heel indicated a strong preference for the *Shorea* vegetation type. This was due to the fact that very few species, which can be lopped as fodder for cattle, were found in the *Shorea* vegetation type and thus had fewer disturbances that made it attractive for females with young calves. Thus, females with young calves clearly preferred to trade off food for safety. The mean cattle densities in the home ranges of radio collared females, who were either pregnant or had young calves at heel, were significantly lower when compared to that of male home ranges. This study has proven beyond doubt that a major influence on ranging and habitat use in the study population is disturbance.

Key words: Asian Elephants, *Elephas maximus*, ranging, home-range, radio-tracking

INTRODUCTION

The size of an elephant's home range gives an indication of the availability of essential resources, restrictions imposed by the size of the respective conservation area or other artificial barriers and the degree of disturbance to which the animal is exposed (Whyte 1996). Areas with plentiful food and water, and minimal disturbance will have smaller home ranges. It can also be small where artificial barriers (e.g. dams, canals and habitat loss due to agricultural settlements in corridor areas) prevent elephants from using a part of their home ranges (Joshua and Johnsingh 1995). It is important from the management point of view to know which elephant groups/ clans have been affected due to such developments because concentration of elephants in a restricted area could also lead to habitat degradation. In several cases, the ecological boundaries and administrative boundaries do not match (Joshua and Johnsingh 1995) and knowledge of elephant movements is critical for preparing management plans in such an area. In addition to crucial information about home ranges, it is also important to understand the foraging behaviour and spatial use of the resources within the home range.

To collect data on the above aspects, Elephants in Rajaji National Park (RNP) have been intensively studied since December 1996 using radio telemetry. Rajaji National Park in conjunction with Corbett Tiger Reserve and the adjoining forest areas have been designated as one of the eleven elephant reserves in India. An estimated population of about 1000 Elephants is found within this tract (Singh 1995). The Elephants in this area have been under assault from human induced causes, such as diversion of land for non-forestry purposes, over-grazing and excessive lopping of trees for fodder, construction of a canal and, road and rail network resulting in habitat fragmentation (Johnsingh *et al.* 1990). RNP, due to its linear shape, has a long boundary, with a sizeable pastoral Gujjar population inside and villages all around the periphery. The main livelihood of the villagers is agriculture. Therefore, to ensure the long-term survival of Elephants, a thorough understanding of their ranging and habitat requirements is indispensable. We conducted a study on Elephants and their habitats with the following objectives:

1. To describe and explain the ranging behaviour of Elephants in the study area and,

2. To analyze seasonal use of vegetation types by

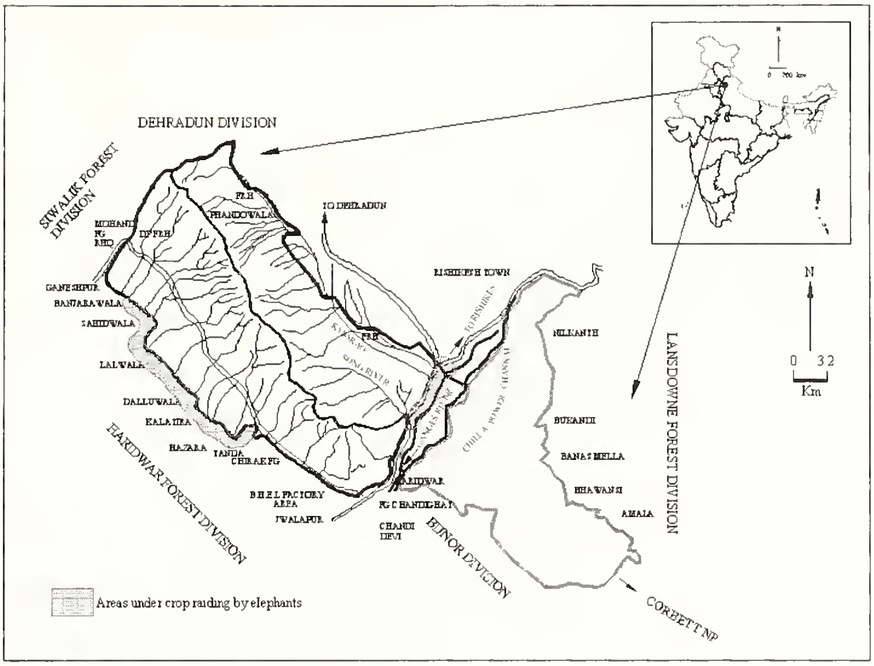

Fig. 1: Map of Rajaji National Park

elephants within the study area and to identify the major factors influencing habitat selection

STUDY AREA

The study was conducted in Rajaji National Park (RNP) west of the River Ganga (Fig. 1). The area includes the Rajaji and Motichur sanctuaries and portions of the Siwalik and Dehradun East Forest Divisions covering an area of approximately 600 sq. km. Topography in the Rajaji Sanctuary area consists of deeply dissected steep southern slopes of the Siwalik hill range, which form a series of sharp ridges interspersed with V-shaped valleys running from north-east to south-west. The southern portion of the Sanctuary is flat land constituting the northern fringe of the Gangetic plain. The altitude ranges from 400 to 1,000 m. There are >4,000 nomadic pastoralists (i.e. Gujjars) and about 8,300 of their livestock (e.g. buffalo, goat etc.) within the study area. These Gujjars are dispersed throughout the study area in small settlements. Over 1,40,000 people live along the periphery of the study area. Their main form of livelihood is agriculture. The study area is bounded by intense cultivation to the north and south, and to the east it is bounded by the suburbs of the town of Haridwar on the bank of the River Ganga. To the west, the Delhi-Dehradun highway separates the Rajaji NP from the Siwalik Forest Division.

Rainfall ranged from 1,300 to 1,900 mm / year during 1996-1999, with most of the rain falling during the monsoon months of July to October. However, there are brief periods of rainfall throughout the year. Three distinct seasons are recognised: winter (November to March), summer (April to June) and monsoon (July to October).

MATERIAL AND METHODS

Four male and four female Elephants were immobilized with Immobilon (a mixture of Etorphine hydrochloride and Acepromazine) delivered with a dart gun, and fitted with radio transmitters embedded on an acrylic collar in Rajaji National Park (Fig. 1). We radio-tracked three males and four females for periods ranging from 1 to 3 years. The Elephants were located 1 to 3 times per week. All animals were located by homing in on the signal and a GPS was used to take a position. All the data was entered into a lotus spread sheet.

We acquired satellite images of approximately of 200 x 200 m resolution and did unsupervised classification using ERDAS IMAGINE (ESRI Inc.) image analysis software. The initial output consisted of 10 different categories of land use as defined by their reflectance values. We then supervised classification and specified five major categories of land use/Forest types. The whole study area was divided into 2 x 2 km grids and 5 random grids were chosen in each of the four categories, which corresponded to the different vegetation/forest type. In these grids, we placed a 2.8 km transect along the diagonals in each grid that had the best access. Along each transect, we measured trees in 10 m radius circular plots every 300 m. For each tree >20 cm diameter at breast height (dbh) within the circular plot, we noted the species and number of branches cut. We also counted the saplings (< 20 cm dbh) of the different tree species in a 5 m circular plot centered within the 10 m circular plot. We then summarised the data to define the four major vegetation types. They were: Sal *Shorea robusta* vegetation, Sal mixed vegetation, Plantation, Miscellaneous vegetation type, Agriculture and, open areas/degraded scrub/rau (dry river beds).

The vegetation types defined here corresponded very closely with the tree species communities defined during an earlier analysis of data, using program TWINSPAN (Two Way INdicator SPecies ANalysis), collected in the study area using similar methods. We chose to limit our analysis to these four major broad vegetation types due to the large home ranges of Elephants in the study area and due to the difficulty in identifying fine differences in vegetation composition in the field.

We then imported the land use/vegetation image into ARCVIEW 3.02a (ESRI Inc.) GIS software to analyze the data on animal locations, Gujjar cattle densities and other information like water availability. We used the ARCVIEW extension ANIMAL MOVEMENT ANALYST (Hooge and Eichenlaub 1997) to analyse the radiolocation data of the seven Elephants. Animal home ranges were defined by 100% Minimum Convex Polygons (MCP) (Mohr 1947) and 95% Fixed Kernels (Worton 1989) of all the locations pooled across seasons and years. MCP method was used so that comparisons of elephant home ranges from other studies could be done. To look at seasonal ranging and habitat use by individual elephants, we used 95% Fixed Kernels (FK) of the seasonal data. We used original Adhoc and LSCV smoothing parameters to provide a less biased estimator than a user selected or Worton's corrections (Hooge and Eichenlaub 1997). We carried out regression analysis of the % increase in home range against the number of locations to see if adequate sampling had been done to describe the seasonal range of the elephant(s).

We plotted the nomadic pastoral habitats within the study area with the help of a hand held GPS (Magellan Trailblazer, Magellan Inc.) and counted the number of pastoralists and their livestock in each of the habitats. We plotted the data and analysed it using ARCVIEW SPATIAL ANALYST extension and created cattle density maps of the study area over which we overlaid the seasonal ranges to calculate the cattle densities within each Elephant's seasonal range.

RESULTS

We captured and collared four adult male and four adult female Elephants between December 1996 and March 1998. One of the collared males was followed only for five months, and hence the data was not used for analysis. The remaining seven animals were followed for periods ranging from ten months to over three years (Table 1). Since the data beyond two years did not significantly add new information to what was analyzed after two years of tracking, we chose to use only 24 months of data to understand the habitat use patterns. The number of collared males represented approximately 10% of the estimated adult male population size in the study area (Williams *et al.* 2007). Female Elephants live in groups of related females and their associated young. Females and young associated with groups containing the collared females represented approximately 33% of the total estimated female and associated young population numbers (Williams *et al.* 2007). The radio-tracked individuals ranged over an area of about 600 sq. km (Fig. 2). Little dung (<1%) was encountered outside this area during the dung surveys, indicating that the entire elephant population (*c.* 180-200) west of the River Ganga largely used this 600 sq. km. However, there were cases of elephant bulls and family groups straying towards Yamuna in the Siwalik Forest Division (Fig. 1). On eastern side, only a few bulls crossed over the Ganges through the Chilla-Motichur corridor. Females did not cross the Rishikesh-Haridwar road.

Ranging

Minimum number of location needed

For the study animals, since ranging and habitat use within a season was of interest, it was necessary to find the

Table 1: Annual home ranges (sq. km) of radio-tracked elephants as calculated by the minimum convex polygon method (MCP) in Rajaji National Park, 1996-2001

Animal ID	No. of locations	No. of months tracked	Home range (MCP)
MaleT	253	24	407.04
MaleS	285	24	188.04
MaleA	123	10	254.72
FemaleM	233	21	183.96
FemaleA	235	24	326.64
FemaleD	211	24	306.28
FemaleK	264	24	251.6

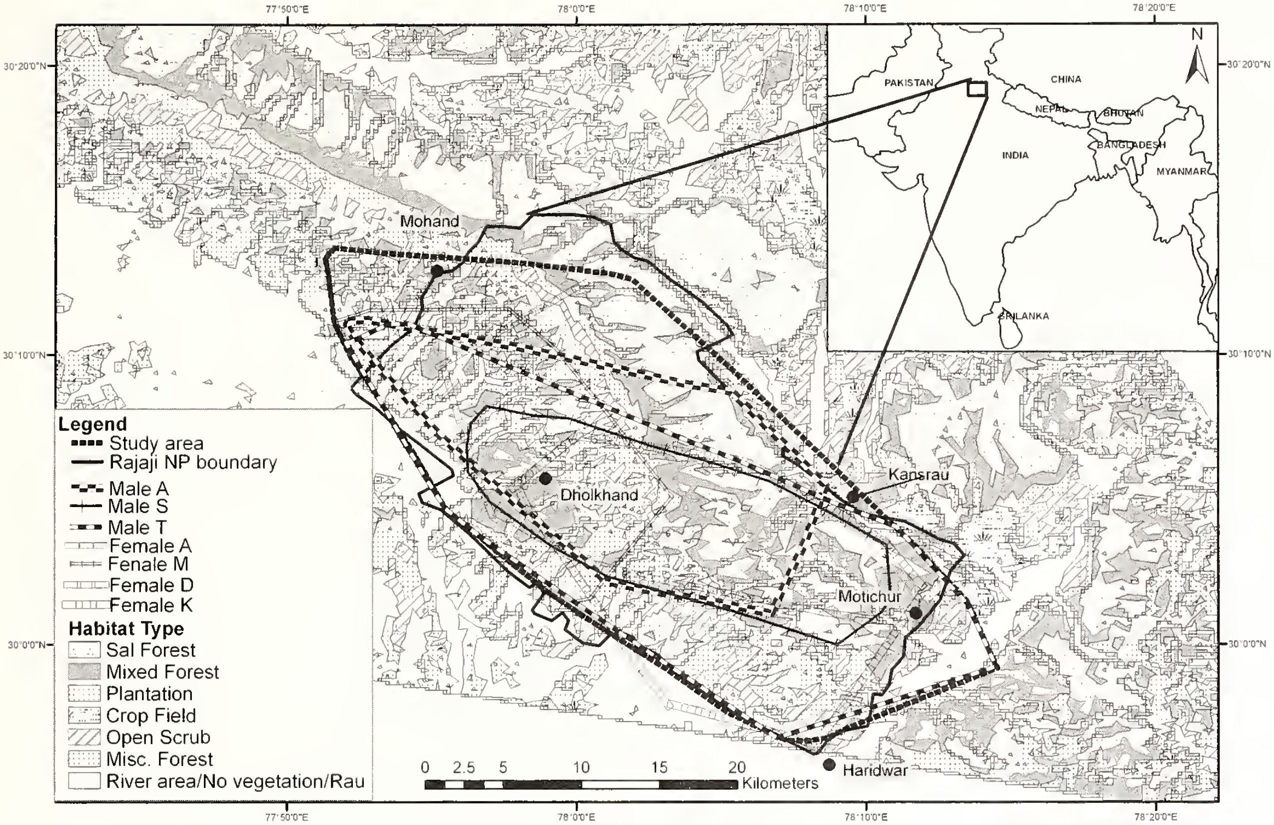

Fig. 2: Home ranges (100% MCP) of the radio collared elephants within the study area

minimum number of locations needed to be sure that the seasonal range had been well described. The relationship between mean percent change in home range estimates and the number of locations needed was asymptotic (Fig. 3). The minimum number of locations needed to estimate fairly accurate seasonal home ranges should have at least two characteristics (Mares *et al.* 1980).

1) All the intervals past the minimum estimate should have mean percent changes in home ranges that are indistinguishable from zero;

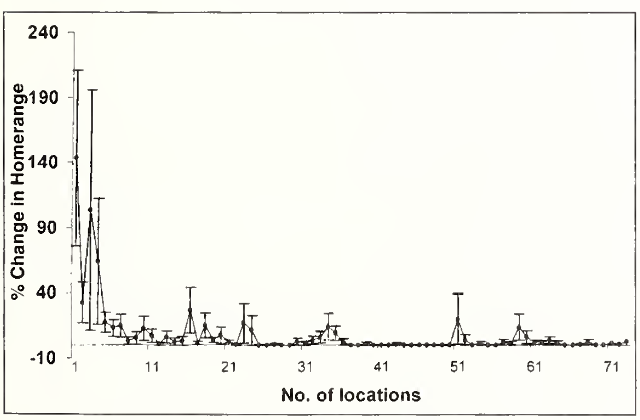

Fig. 3: Mean and SE of % change in home ranges (N=7 elephants) with successive locations

2) A constant relationship should exist for all locations intervals past the minimum estimate (i.e. a regression line whose slope is zero should exist).

Both of these criteria were met for Elephants at between 20 and 30 relocations per season (Fig. 3). The mean ±1 SE for all points between 20 and 30 locations contain zero and an insignificant linear relationship (Table 2) exists for data points greater than the 25th location (i.e. the slope of the regression line is not statistically distinguishable from zero).

Annual and seasonal range estimates

Elephants had home ranges (100% MCP) from188 sq. km to >400 sq. km (Table 1). However, there seems to be no difference in annual home ranges between males and females. There was large variability in the seasonal ranges between elephants, seasons, and years (Table 3). There were no

Table 2: Linear regression in an ANOVA setting (Excel spreadsheet function); mean percent change in home range as a function of number of locations

Source of variation	df	SS	MS	F	P
Due to regression	1	0.1569	0.1569	0.160	0.690
Residual	47	45.98252	0.9783		
Total	48	46.13942			
Multiple r^2 = 0.003401					

difference in ranges between seasons when pooled across sexes and years (Kruskal-Wallis one way ANOVA, $\chi^2 = 1.7709$, 2 df, P = 0.41). Summer ranges (95% FK) were the smallest of the three seasons (Table 4). Males had larger summer seasonal ranges than females (Mann-Whitney test, U = 2.0, P = 0.01). There was no difference in the seasonal ranges between male and female elephants in winter and monsoon. All the 6 elephants (2 males and 4 females) that were tracked for 2 annual cycles showed variability in ranging patterns between the 1st and 2nd years. Summer ranges were rather small or linear in shape when compared to the ranges of the same individual or group for monsoon and winter. For example, Male T and Female A ranged more widely in the monsoon of 1998 when compared to the same season in the previous year (Tables 3 & 4). The MCP estimates in Table 3 were better suited at reflecting occasional wandering by the Elephants than the 95% FK estimates in Table 4. Hence, the following section refers mainly to estimates from Table 3. Males T and A came into musth in winter while Male S came into musth in summer. All the males consistently used large ranges during their musth period and were wandering widely (Table 3). Females M and D gave birth to calves in 1997 and 1998 monsoon season respectively. Their seasonal ranges in winter and summer following calving were approximately 25 to 50% of their seasonal ranges the previous year (Table 3). There was a vast difference in ranging patterns of the female M and her group between the two years that they were tracked. In the year 1998-99, she altogether abandoned the southern side of the Park and spent the entire period in the northern half of the Park before being run over and killed in a train accident near the main road on the east.

Female D exhibited similar behaviour by spending most of the time in areas of fewer disturbances during winter and summer following the birth of her calf. However, her monsoon ranging pattern remained unchanged.

Seasonal use of vegetation types

Males avoided the use of *Shorea* forests during winter and monsoon, and to a large extent used the other vegetation types in proportion to their availability (Table 5). Females, on the other hand, used the mixed-plantations, miscellaneous vegetation, open degraded scrub and riverbeds (Table 5) less than expected. Females (M, D and K) which were either pregnant or had young calves at heel during the period that they were radio tracked showed either strong selection or avoidance of vegetation types (Table 7). *Shorea*-mixed vegetation type was either selected or used in proportion to availability by all the females (Table 5). All the Elephants

Table 3: Seasonal home ranges (sq. km) of elephants calculated by the Minimum Convex Polygon method (MCP) in the various seasons in Rajaji National Park (1996-1999)

Year/Animal	Season					
	Winter (Nov.-Mar.)		Summer (Apr.-Jun.)		Monsoon (Jul.-Oct.)	
	No. of locations	MCP	No. of locations	MCP	No. of locations	MCP
1996-97						
MaleT	53	248.92	29	86.60	39	148.52
MaleS	51	74.56	33	79.12	50	78.64
FemaleM	50	90.28	24	84.24	40	83.32
FemaleA	32	110.4	36	57.24	35	37.12
FemaleD					45	114.36
FemaleK					48	136.96
1997-98						
MaleT	71	307.68	32	181.00	29	257.84
MaleS	72	53.48	32	112.44	47	84.12
MaleA			50	52.32	55	124.28
FemaleM	53	46.92	36	26.00	30	63.12
FemaleA	64	65.96	30	72.76	38	147.4
FemaleD	54	208.12	25	42.84	28	139.36
FemaleK	67	129.48	37	98.24	31	145.60
1998-99						
MaleA	18	192.6				
FemaleD	42	52.48	17	17.2		
FemaleK	59	152.32	22	27.32		

avoided *Shorea* forests during the 1997 monsoon (Table 5). The same ranging pattern was observed in the monsoon of 1998, when the Elephants largely avoided *Shorea* forest, except for females D and M which had young calves at heel.

Human and cattle densities within the study area were highly correlated (Spearman's r = 0.66, P<0.0001, n=321). Hence, we used only cattle densities as an index of disturbance. The density of cattle was higher inside the home ranges of collared males when compared to that of collared females (Table 6). Only Female K tolerated disturbance (as measured by cattle densities) at levels tolerated by males in the monsoon season (Table 6). If the monsoon season was excluded from the analysis, the mean cattle density in the home ranges of females (K, D & M) that were pregnant or had young calves at heel was much lower when compared to the males (Table 6). However, Female A, which was neither visibly pregnant nor had a young calf at heel, used areas with disturbance comparable to the area with cattle density (mean = 27.7 cattle/sq. km and S.D.=1.5) used by males.

The densities of important food plants of Elephants were highest in *Shorea* vegetation type (Table 7). Even when *Shorea* was excluded from the plants considered, *Shorea* vegetation type still had the highest densities of important elephant food plants (Table 7), and this was mainly due to the contribution of *Mallotus phillippensis*. However, *Shorea* was the least used among the vegetation types (Table 5), except for females that had young calves at heel. When we looked at diversity and density of major elephant food plants in the four vegetation types, *Shorea*-mixed and miscellaneous vegetation type had the highest diversity of elephant food plants.

Water was available everywhere during the monsoon season and therefore, we did not consider the monsoon season when testing for differences between seasons. We could not detect a statistical difference in the distance to water between winter (Mean ± SE=1,311.69 ±83.59) and summer (Mean ± SE = 1,299 ± 41.48) seasons pooled across animals (T = 0.13, df = 17 , P = 0.89) and years.

DISCUSSION

Ranging and habitat use by elephants have been studied before in African and Asian elephant populations (Douglas-Hamilton 1972; De Villiers and Kok 1997; Baskaran *et al.*

Table 4: Seasonal home ranges (sq. km) of elephants calculated as 95% fixed kernels (FK) in the various seasons in Rajaji National Park (1996-1999)

Year/Animal	Season					
	Winter (Nov.-Mar.)		Summer (Apr.-Jun.)		Monsoon (Jul.-Oct.)	
	No. of locations	FK	No. of locations	FK	No. of locations	FK
1996-97						
MaleT	53	281.04	29	142.48	39	71.6
MaleS	51	52.36	33	125.04	50	108.48
FemaleM	50	49.0	24	69.4	40	48.96
FemaleA	32	79.36	36	70.36	35	53.92
FemaleD					45	181.32
FemaleK					48	30.76
1997-98						
MaleT	71	239.84	32	181.24	29	405.2
MaleS	72	66.16	32	190.92	47	144.84
MaleA			50	72.12	55	146.2
FemaleM	53	60.16	36	23.96	30	69.24
FemaleA	64	109.12	30	80.4	38	180.2
FemaleD	54	209.28	25	83.2	28	175.72
FemaleK	67	169.0	37	53.48	31	67.84
1998-99						
MaleA	18	349.68				
FemaleD	42	130.0	17	33.6		
FemaleK	59	208.92	22	33.6		
Mean		154.15		94.65		129.56
SE		27.05		15.37		27.40

Table 5: Selection and Avoidance of the vegetation associations by elephants in Rajaji National Park

			Vegetation association[a]				
Season/Animal	No.	χ^2	*Shorea*	*Shorea*-mix	Mixed-plantations	Miscellaneous	Others[b]
Males							
1996-97 Winter							
MaleT	53	13.1	A				
MaleS	51	16.42	A				
1997-98 Winter							
MaleT	71	19.17	A				S
MaleS	72	26.25	A				
1997 Summer							
MaleT	29	10.94		A			
MaleS	33	8.93					
1998 Summer							
MaleT	32	7.73					
MaleS	32	8.62					
MaleA	50	11.62					
1997 Monsoon							
MaleT	39	44.54	A	A		S	
MaleS	50	9.75					
1998 Monsoon							
MaleT	29	18.02	A				
MaleS	47	10.27	A				
MaleA	55	6.16	N				
Females							
1996-97 Winter							
FemaleM	50	5.62					
FemaleA	32	6.65					
1997-98 Winter							
FemaleM	53	41.29	S	S	A	A	A
FemaleA	64	11.76	A				
FemaleD	54	17.19					A
FemaleK	67	7.41					
1998-99 Winter							
FemaleD	42	46.6	S		A	A	A
FemaleK	59	9.78					
1997 Summer							
FemaleM	24	20.62		S	A		
FemaleA	36	0.81					
1998 Summer							
FemaleM	36	12.82			A		
FemaleA	30	4.82					
FemaleD	25	20.48	S		A	A	
FemaleK	37	17.68					
1999 Summer							
FemaleD	17	30.94			A	A	
FemaleK	22	10.25					
1997 Monsoon							
FemaleM	40	18.64	A				A
FemaleA	35	22.48	A			S	
FemaleD	45	8.97					
FemaleK	35	22.48	A	A			
1998 Monsoon							
FemaleM	30	32.83	S		A		A
FemaleA	38	7.5					
FemaleD	28	14.44			A		
FemaleK	31	9.42	A				

[a]S = association use > expected; A = association use < expected; N = no use of the habitat recorded;
blank cells = association use proportional to availability (P = 0.05) (Byers *et al.* 1984);
[b] = includes open scrub, grasslands and river beds.

1995; Mckay 1973). This is the first study in Asia where the proportion of elephants, for whom ranges have been described, has been reported (see results). After this study, we have an accurate and fairly descriptive measure of the ranging patterns of adult males and female groups in RNP. Most of the elephant ranging seems to be confined to the National Park boundaries to the west of River Ganga unlike on the other side, where Joshua and Johnsingh (1995) found that 40-60% of two elephants home ranges were outside the RNP area boundary. There seems to be very few groups using the Siwalik Forest Division. However, as the densities inside the Park increase more and more elephants will start using areas outside, such as the Siwalik and Dehradun Forest divisions. The population seems to be a closed one; we could find evidence for only about 3 bulls' crossing over Ganga from Motichur to Chilla side of RNP.

Elephant home ranges recorded, so far, vary widely depending on the elephant population and the ecological conditions under which they were studied. The results from this and earlier studies (Joshua and Johnsingh 1995) indicate that adult male home ranges in RNP vary widely ranging from about 160 sq. km to over 400 sq. km. An earlier study on the Chilla side of RNP concluded that the small home range recorded (approx. 39 sq. km) for a single adult female was due to her home range being lost to developmental activity (Joshua and Johnsingh 1995). This seems to be supported by the results of our study where the smallest female home range was about 200 sq. km. Most studies on African elephants have showed a strong relationship between rainfall and home range size. Home ranges of elephants in areas of higher rainfall (Tsavo west – 750 sq. km) were smaller than the ranges of elephants in areas of low rainfall (Tsavo east – 1,600 sq. km). Thouless (1996) showed similar results from his study in northern Kenya, where the home ranges varied between 102 sq. km (high rainfall area) to 5,527 sq. km (low rainfall area). However, human disturbance also played a significant role in influencing the range sizes. The home ranges of two adult females tracked in northern Cameroon were 3,066 sq. km and 2,484 sq. km respectively (Tchamba *et al.* 1995), and it is thought that intensity of the elephant-human conflict forced the two elephants to move long distances resulting in large home ranges. De Villiers and Kok (1997) estimated, after six years of radio tracking in two nature reserves adjacent to Kruger National Park, that female home ranges varied between 115 sq. km and 342 sq. km, whereas male home ranges were between 150 sq. km and 342 sq. km. They showed that availability of water played an influencing role on the size of the elephant home ranges in the two reserves. In Asia, however, home range sizes reported (males: 160-400 sq. km; females: 40-650 sq. km) are much lower due to the elephants living in mainly forested habitats with higher rainfall than recorded across many of the African studies sites (Joshua and Johnsingh 1995; Baskaran *et al.* 1995).

Table 6: Cattle densities (No./sq. km) in the seasonal home-ranges of male and female elephants in Rajaji National Park 1996-99

Sex	Cattle densities: With monsoon season		Without monsoon season	
	Mean (n)	SE	Mean	SE
Male	29.70 (15)	1.72	26.59 (10)	1.26
Female	23.71 (24)	2.94	15.88 (12)[1]	0.79
Mann-Whitney U	72		2	
P	0.0018		0.0001	

[1] = Densities calculated for females, K, D & M, that were either pregnant or had calves at heel during the study period.

Individual home ranges also overlapped considerably within and between sexes in the study area as noticed in other studies on elephants elsewhere (Leuthold 1977; Jachmann 1992; Thouless 1995; Sukumar 1991; Baskaran *et al.* 1995; Joshua and Johnsingh 1995). However, De Villiers and Kok (1997) found that females tend to avoid each other inside their core areas (defined as 10% of their home range) and explained this as a mechanism under which high densities of elephants are able to tolerate each other in a small area. The density of elephants in our study area was low (<0.4/ sq. km) compared to that of other areas (1-4/sq. km) where detailed elephant studies have been carried out. We could not carry out this analysis, since there were groups which did not have radio collared individuals overlapping with our study animals. We, however, noticed that even though three radio collared female groups were in the general vicinity during the dry season, we located them together only once in two years of tracking. There seems to be very little temporal overlap between the female groups within the study area.

The summer ranges were smaller than other seasons due to the limited availability of water in the study area

Table 7: The densities (No./Ha) of important elephant forage trees in four vegetation types in Rajaji National Park

Vegetation type	Forage tree density: With *Shorea robusta*		Without *Shorea robusta*	
	(Mean)	SE	(Mean)	SE
Shorea	578.31	40.45	298.84	21.36
Shorea-mix	277.41	24.32	251.30	25.66
Mix-plantations	162.21	20.45	156.78	20.11
Miscellaneous	86.15	14.63	74.51	13.22

(Tables 3 & 4). Elephants showed a greater fidelity in the dry season than in the other seasons, except for Female K who showed a high degree of fidelity across all seasons. This is consistent with other studies on elephants where water was a limiting factor in Africa (Leuthold 1977; Viljoen 1989a, b; Thouless 1995).

Elephants in this area also showed a high degree of fidelity with regard to dry and wet season, which was in contrast to the elephants of Tsavo (Leuthold 1977). Another point to note in the present study was that both females D and M changed their ranging pattern from previous years immediately following the birth of a newborn calf. Thus, this study also proves that elephants show considerable flexibility in ranging behaviour to improve their chances of survival. They also had smaller dry season home ranges, a result similar to the one reported by De Villiers and Kok (1997). The temperatures in the study area rose as high as 42 °C during summer. Females remained near permanent water sources during summer, as it would probably be detrimental to the survival of calves to move widely in search of food during such temperatures. Also the females with young calves (D, M and K) used permanent water sources in areas of low disturbance.

Very few studies have reported increases in seasonal ranges due to adult males coming into *musth* (equivalent to rut) (Joshua and Johnsingh 1995). T and A came into *musth* in winter, while S came into *musth* in summer. We found that all three adult males that we followed were given to wandering widely in search of females during *musth* and consequently had large ranges during *musth* when compared to other seasons (Table 3). In rainy season of 1997-98 Male T shifted between two areas, and hence a large home range was recorded. Similarly, Joshua and Johnsingh (1995) reported that a male, which was radio-tracked for over two years, increased its seasonal range from 22 sq. km in the monsoon to over 200 sq. km in winter (it's *musth* season).

Elephants in RNP seem to use *Shorea*-mixed vegetation type much more than the other vegetation types (A. Christy Williams, unpubl data). This seems to be consistent even with selection at an individual level, where *Shorea*-mixed vegetation was the least avoided. *Shorea* vegetation had the lowest dung densities indicating minimal elephants use (A. Christy Williams, unpubl data). However, individual elephants, having young calves that were radio tracked for over two years showed strong selection for the *Shorea* vegetation. This is mainly due to the fact that very few species that can be lopped are found in this vegetation type and therefore avoided by the Gujjars to a large extent, and thus less disturbed than the other vegetation types (Williams *et al.* 2002). During the monsoon season females and males used the miscellaneous vegetation in proportion to availability or selected it in a few cases. We believe this is due to the abundance of green grasses such as *Dolichostachya* and the presence of the bamboo *Dendrocalamus strictus*, important food sources for elephants during monsoon. Elephants in the study area eat a large amount of grass in the wet season, even if they appear to like browse at other times and this seems to be consistent from other studies in Africa (Buss 1961; Field 1971; Laws *et al.* 1975). Seasonal changes in habitat selection and diet have been observed in different elephant populations across Africa and Asia (Buss 1961; Field 1971; Mckay 1973; Laws *et al.* 1975; Leuthold 1976; Olivier 1978; Barnes 1982; Sukumar 1991; Sivaganesan and Johnsingh 1995) indicating the relative opportunistic nature of the diet of elephants. They are able to utilize a wide selection of food available from ground level up to 4-5 m, and thus are able to survive even tough environmental conditions like drought and unpredictable rainfall.

The distribution and availability of water governs the distribution of elephants (Laws 1970; Kerr and Fraser 1975). Outside the monsoon season water availability in the study area is restricted to the foothills of the Siwaliks. In summer, water availability becomes restricted to small pools along the *raus*. Yet, we failed to detect any differences in distance to water between the winter and summer seasons for the study animals indicating elephants at all times used areas nearer to water.

This study has proved that a major influence on ranging and habitat use in Elephants is disturbance. Female Elephants with calves do not tolerate disturbance and females respond to disturbance by moving into areas with fewer cattle. Thus, resettling *Gujjars* outside the Park area has to be given priority and encouraged to free more areas of human disturbance. We have already seen that the Elephant population in the study area is demographically very viable (Williams *et al.* 2007) and therefore, as the elephant population increases, need for more areas with fewer disturbances is essential. The Elephants in the study area are still using a compact block of forest and hence elephant-human conflict can be managed easily. As the density of elephants increase in the study area, elephant groups at the periphery of this range will be forced to use areas outside the Park boundaries. It is these areas which have a very high level of disturbance where elephant-human conflict would be severe. Therefore, it is necessary to plan an elephant habitat management plan for this elephant range that takes into account all the above factors and addresses the issue of habitat degradation outside the study area in the adjacent Siwalik and Dehradun Forest divisions. A positive step in this direction is the recent moves to resettle *Gujjars* outside the Park. The impact of this reduction in disturbance on elephant ranging will be interesting to study in the future.

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